

What is claimed is:

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1. A gas treatment apparatus for reducing the hazardous gas content of an effluent from a process chamber, the gas treatment apparatus comprising:
- (a) an exhaust tube for exhausting the effluent from the process chamber; and
- (b) a gas energizer for energizing the effluent flowing through in the exhaust tube to reduce the hazardous gas content of the effluent.
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2. The gas treatment apparatus of claim 1 wherein the exhaust tube comprises a length that is sufficiently long to reduce the hazardous gas content of a continuous stream of effluent flowing through the exhaust tube without recirculation the effluent in the exhaust tube.
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3. The gas treatment apparatus of claim 1 wherein the exhaust tube comprises a length that is sufficiently long to provide a residence time of the effluent flowing through the exhaust tube that is at least about 0.01 seconds.
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4. The gas treatment apparatus of claim 1 wherein the exhaust tube comprises a flow surface that provides a laminar flow of effluent through the exhaust tube.
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5. The gas treatment apparatus of claim 4 wherein the exhaust tube comprises a cylinder having an internal flow surface that is parallel to the direction of the flow of the effluent through the exhaust tube, and that is substantially absent projections or recesses that alter the effluent flow path.

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6. The gas treatment apparatus of claim 1 further comprising a reagent gas mixer for mixing reagent gas with the effluent to further reduce the hazardous gas content of the effluent.

5 7. The gas treatment apparatus of claim 1 wherein the exhaust tube is composed of monocrystalline sapphire, and the gas energizer comprises a microwave generator for generating microwaves and a waveguide for coupling microwaves from the microwave generator to the exhaust tube to energize the effluent by microwaves.

10 8. The gas treatment apparatus of claim 1 wherein the gas energizer comprises a plasma generator for coupling RF energy into the exhaust tube to form a plasma from the effluent, the plasma generator comprising facing electrodes or an inductor coil.

15 9. The gas treatment apparatus of claim 1 wherein the exhaust tube comprises a distributor plate at an inlet of the exhaust tube, the distributor plate having holes for directing effluent preferentially along a flow surface of the exhaust tube.

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20 10. The gas treatment apparatus of claim 1 further comprising:

(a) a gas analyzer for monitoring the hazardous gas content of the effluent in the exhaust tube and providing an output signal in relation to the hazardous gas content of the effluent; and

25 (b) a computer controller system comprising a computer readable medium having computer readable program code embodied therein for monitoring the output signal from the gas analyzer, and when the hazardous gas content of the effluent exceeds a safety level, performing at least one of the steps of:

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- (i) adjusting the operating power level of the gas energizer to reduce the hazardous gas content in the effluent,
 - (ii) adjusting the process conditions in the process chamber to reduce the hazardous gas content in the effluent,
 - (iii) activating an alarm or metering display,
 - (iv) adding a reagent gas to the effluent gas before or after the effluent gas is energized, to reduce the hazardous gas content in the effluent, or
 - (v) terminating the process being conducted in the process chamber.
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11. A process chamber for processing a substrate and reducing emissions of hazardous gas to the environment, the process chamber comprising:

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- (a) a support for supporting the substrate in the process chamber;
 - (b) a gas distributor for introducing process gas into the process chamber;
 - (c) a gas activator for activating the process gas to process the substrate, thereby forming an effluent containing hazardous gas; and
 - (d) an exhaust system for exhausting and treating the effluent from the process chamber, the exhaust system comprising an exhaust tube for flowing a continuous stream of the effluent therethrough, and a gas energizer for energizing the effluent in the exhaust tube to reduce the hazardous gas content of the effluent.
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12. The process chamber of claim 11 wherein the exhaust tube comprises at least one of the following characteristics:

(1) a length that is sufficiently long to reduce the hazardous gas content of the continuous stream of effluent flowing through the exhaust tube without recirculation the effluent in the exhaust tube;

(2) a length that is sufficiently long to provide a residence time of effluent in the exhaust tube that is at least about 0.01 seconds; or

(3) a flow surface that provides a laminar flow of effluent through the exhaust tube, the flow surface being parallel to the direction of the flow of the effluent through the exhaust tube and substantially absent projections or recesses that alter the effluent flow path.

13. The process chamber of claim 11 wherein the gas energizer comprises a microwave generator for generating microwaves and a waveguide for coupling microwaves from the microwave generator to the exhaust tube to energize the effluent in the exhaust tube.

14. The process chamber of claim 11 wherein the gas energizer comprises a plasma generator for coupling RF energy into the exhaust tube to generate a plasma from the effluent in the exhaust tube, the plasma generator comprising facing electrodes or an inductor coil.

15. The process chamber of claim 11 wherein the exhaust tube is composed of monocrystalline sapphire.

16. The process chamber of claim 11 further comprising:
(a) a gas analyzer for monitoring the hazardous gas content of the effluent in the exhaust tube and providing an output signal in relation to the hazardous gas content of the effluent; and

(b) a computer controller system comprising a computer readable medium having computer readable program code embodied therein for monitoring the output signal from the gas analyzer, and when the hazardous gas content of the effluent exceeds a safety level, performing at least one of the steps of:

- (i) adjusting the operating power level of the gas energizer to reduce the hazardous gas content in the effluent,
- (ii) adjusting the process conditions in the process chamber to reduce the hazardous gas content in the effluent,
- (iii) activating an alarm or metering display,
- (iv) adding a reagent gas to the effluent gas before or after the effluent gas is energized, to reduce the hazardous gas content in the effluent, or
- (v) terminating the process being conducted in the process chamber.

17. A method of reducing the hazardous gas content of an effluent formed during processing of a semiconductor substrate, the method comprising the steps of:

- (a) flowing a continuous stream of the effluent through an exhaust tube; and
- (b) coupling microwaves or RF energy into the exhaust tube to reduce the hazardous gas content in the continuous stream of effluent flowing through the exhaust tube without recirculation of the effluent in the exhaust tube.

18. The method of claim 17 wherein step (a) comprises the step of flowing the effluent through a path length that is sufficiently long to reduce the hazardous gas content of the effluent as a continuous stream of effluent flows through the exhaust tube.

19. The method of claim 17 wherein step (a) comprises the step of flowing the effluent through a path length that is sufficiently long to provide a residence time of effluent in the exhaust tube that is at least about 0.01 seconds.

20. The method of claim 17 wherein step (a) comprises the step of flowing the effluent in a substantially laminar flow through the exhaust tube.

21. The method of claim 17 further comprising the step of introducing a reagent gas into the effluent to further reduce the hazardous gas content of the effluent.

22. The method of claim 21 wherein the volumetric flow ratio of reagent gas to effluent is sufficiently high to abate substantially all the hazardous gas content of the effluent.

23. The method of claim 17 further comprising the steps of:

- (1) analyzing the hazardous gas content of the effluent emitted from the exhaust tube; and
- (2) determining if the content of the hazardous gas in the effluent emitted from the exhaust tube exceeds a safety level, and upon such determination, performing at least one of the steps of:
 - (i) adjusting the operating power level of the gas energizer to reduce the hazardous gas content in the effluent,
 - (ii) adjusting the process conditions in the process chamber to reduce the hazardous gas content in the effluent,
 - (iii) activating an alarm or metering display,
 - (iv) adding a reagent gas to the effluent gas before or after the effluent gas is energized, to reduce the hazardous gas content in the effluent, or

process chamber.

(v) ~~terminating~~ the process being conducted in the

24. A process chamber for processing a substrate in a process gas and reducing emissions of hazardous gas to the environment, the process chamber comprising:

- (a) a support for supporting the substrate;
- (b) a gas distributor for introducing process gas into the process chamber;
- (c) a gas activator for activating the process gas to process the substrate thereby forming effluent containing hazardous gas; and
- (d) an exhaust system for exhausting and treating effluent from the process chamber, the exhaust system comprising an exhaust tube composed of monocrystalline sapphire, a microwave source for generating microwaves, and a waveguide for coupling microwaves from the microwave source to the exhaust tube, whereby energizing the effluent in the exhaust tube by microwaves reduces the hazardous gas content of the effluent.

25. The process chamber of claim 24 wherein the exhaust tube comprises at least one of the following characteristics:

- (1) a length that is sufficiently long to reduce the hazardous gas content of a continuous stream of effluent flowing through the exhaust tube without recirculation the effluent in the exhaust tube;
- (2) a length that is sufficiently long to provide an effluent residence time in the exhaust tube that is at least about 0.01 seconds; or
- (3) a flow surface that provides a laminar flow of effluent through the exhaust tube, the flow surface being parallel to the direction of the flow of the effluent through the exhaust tube and substantially absent projections or recesses that alter the effluent flow path.

26. A process chamber for processing a semiconductor substrate in a process gas while reducing emissions of a hazardous gas to the environment, the process chamber comprising:

(a) a support for supporting the substrate, a gas distributor for introducing process gas into the process chamber, and a gas activator for activating the process gas to process the substrate, thereby forming effluent containing hazardous gas;

(b) an exhaust system comprising an exhaust tube for exhausting the effluent from the process chamber and a gas energizer for energizing the gas in the exhaust tube to reduce the hazardous gas content of the effluent;

(c) a gas analyzer for monitoring the hazardous gas content of the effluent in the exhaust tube and providing an output signal in relation to the hazardous gas content of the effluent; and

(d) a computer controller system comprising a computer readable medium having computer readable program code embodied therein for monitoring the output signal from the gas analyzer, and when the hazardous gas content of the effluent exceeds a safety level, performing at least one of the steps of:

(i) adjusting the operating power level of the gas energizer to reduce the hazardous gas content in the effluent,

(ii) adjusting the process conditions in the process chamber to reduce the hazardous gas content in the effluent,

(iii) activating an alarm or metering display,

(iv) adding a reagent gas to the effluent gas before or after the effluent gas is energized, to reduce the hazardous gas content in the effluent, or

(v) terminating the process being conducted in the process chamber.

27. The process chamber of claim 26 wherein the computer readable program code on the computer readable medium comprises one or more of:

- 5 (1) gas analyzer program code for receiving the output signals relating to the hazardous gas content of the effluent from the gas analyzer, and storing or passing the output signals to other program codes,
- (2) gas energizer program code for adjusting a power level of a gas energizer in relation to the output signals,
- 10 (3) reagent gas program code for operating a reagent gas mixer that adds reagent gas to the effluent in relation to the output signals, and
- (4) safety operational program code that upon receiving an output signal that the hazardous gas content of the energized effluent exceeds a safety level, performs at least one of the steps of (1) adjusting process conditions in the process chamber to reduce the hazardous gas emissions, (2) operating an alarm to indicate a dangerous level of toxic or hazardous gas in the effluent, (3) providing a metering display that shows in real time the level of emissions of hazardous gas, or (4) shutting down the process chamber.

28. A computer program product for operating a gas treatment apparatus and process chamber, to reduce the hazardous gas content of an effluent formed during processing of a semiconductor substrate in the process chamber,

the gas treatment apparatus comprising an exhaust tube for exhausting effluent from the process chamber, a gas energizer for energizing the effluent in the exhaust tube to reduce the hazardous gas content of the effluent, and a gas analyzer for monitoring the hazardous gas content of the effluent in the exhaust tube and providing an output signal in relation to the hazardous gas content of the effluent,

the computer program product comprising a computer usable medium having computer readable program code embodied in the medium, the computer readable program code comprising:

- 5 (a) gas analyzer program code for receiving the output signal relating to the hazardous gas content of the effluent from the gas analyzer, and storing or passing the output signal to other program codes; and
- 10 (b) safety operational program code that upon receiving an output signal that the hazardous gas content of the energized effluent exceeds a safety level, performs at least one of the steps of (1) adjusting process conditions in the process chamber to reduce the hazardous gas emissions, (2) operating an alarm to indicate a dangerous level of toxic or hazardous gas in the effluent, (3) providing a metering display that shows in real time the level of emissions of hazardous gas, or (4) shutting down the process chamber.

15 29. The computer program product of claim 28 wherein the computer readable program code comprises gas energizer program code for adjusting a power level of the gas energizer in relation to the output signal to reduce the hazardous gas emissions of the effluent.

20 30. The computer program product of claim 28 wherein the computer readable program code comprises reagent gas program code for adding reagent gas to the effluent in relation to the output signal to reduce the hazardous gas emissions of the effluent.

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